The horizontal load test on pressure-injected piles in damped subsiding Soils

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Abstract. In connection with the needs of the present, the question of the optimal design of building foundations, taking into account the regional characteristics of loess-like silty clay soils, common in Mongolia, becomes relevant. In recent years, in the Orkhon-Selenginsky region and especially in the Darkhan region, industrial and civil buildings and engineering structures are being actively built up and planned to regulate the problems of overpopulation and smoke in the city of Ulaanbaatar, Mongolia. The regularity of the process of changing the stress-strain state of loess-like subsidence soils of the base due to technogenic moistening is subject to the general theory of subsidence soil mechanics, but each region of the world has its own distinctive feature depending on territorial and climatic conditions. Settling clayey soils of Mongolia in their natural state have a relatively high content of water-soluble and slightly soluble carbonate and other salt compounds and, due to their cemented and crystallized structural bonds, they have relatively high mechanical properties, but the mechanical properties, due to the weakening of structural bonds during soaking, sharply decrease to a value of $c = 7.0…10.2$ kPa, $\varphi = 16….÷20°$, $E = 3.5…4.5$ MPa and subsidence begins depending on the type of soil at pressure $P = 0,15$ MPA and $W = (6.7…8.6)\%$ or W_{sat}, while the relative subsidence index is $\varepsilon_{sl} > 0.01$. At pressure $P = 0,2$MPa and $W = (6.1…7.6)\%$, subsidence begins, and at pressure $P = 0.25$MPa and $W = (5.2…6.9)\%$ drawdown begins. These moisture values are calculated respectively at the given pressures as the initial settling moisture W_{sl}. This article discusses the results of field tests of bored piles for a horizontal load, taking into account the moistening of the subsidence soil of the foundation of buildings and structures.

1 Introduction

In Mongolia, the loessial subsiding soils are of cryogenic, subliminal nature, marked by low moisture content and high degree of fragmentation [1-3]. Exposed to technogenic damping

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and flooding, the foundations of buildings and structures subside [4], while loessial clay soils, exposed to seasonal deep freezing, heave in different directions and to varying degrees, leading to excessive settlements in buildings [5, 6]. As a result, many buildings experience excessive, even unacceptable, deformations, requiring considerable funds and time for their repair. Unfortunately, reinforcement and repairs do not result in buildings restoring to the state prescribed by regulatory documents [7-9], especially the regulations pertinent to seismic engineering. The territory of Mongolia is classified as an earthquake-prone region.

Therefore, the engineering and geological studies into the properties of loess-like subsiding soils of Mongolia; modeling and design calculation methods; experimental methods for determining load-bearing capacity and subsidence in piled foundations, among other types of foundations, under different loads and dampness degrees are of particular scientific and practical relevance [10-11].

2 Engineering and geological conditions of the test site

In August and September 2020, we conducted horizontal load tests on two pressure-injected concrete piles. The chosen test site is located near the building of Mongolian State University of Science and Technology's campus in Darkhan, and is represented by loessial silt sandy loam. The physical and mechanical properties of test site soil are given in Table 1.

Table 1. The physical and mechanical properties of test site soil

Pos.	Parameter	Index	Unit of measumenet	Silt sandy loam	Clay loam
1	Natural moisture content	W	Unit fraction	0.051	0.070
9	Porosity coefficient	e	Unit fraction	0.59	0.42
10	Degree of saturation	S_r	Unit fraction	0.41	0.48
12	Average moisture content after damping	$Wsat$	Unit fraction	0.16	0.082
13	Average saturation after damping	S_r	Unit fraction	0.87	0.56
12	Cohesion	C'	kPa/g/cm^3	10.8/0.11	22.4/0.22
		C''	kPa/g/cm^3	6.8/0.07	
13	Internal friction angle	φ'	degree	23	2.7
		φ''	degree	17	
14	Strain modulus	E	mPa/g/cm^2	11	23
		E_{sat}	mPa/g/cm^2	4.2	
15	Design resistance	R_o	kPa/kg/cm^2	200/2.0	300/3.0

3 Test method

For testing the two pressure-injected concrete piles with a diameter of 0.6 m and a length of 8.0 m, we used casing pipe with a diameter of 0.62 m, which was removed after concreting. Concrete class: B20, without additives. Working reinforcement class: A450. Transverse reinforcement class: A240. After the three-day period of concrete strength development, 1.5x1.5x0.3(h) holes were dug near each pile for the continuous supply, during 34 days, of water from the municipal pipeline (approximately 10 m^3 of water). Prior to the start of the test, a well was drilled for sampling and measuring of moisture content of the near-bottom soil. Based on moisture measurement results, the soil continued to be damped until they reached the water-saturated state (Table 1). The piles were driven under horizontal load using hydraulic jack D-100, in 6 stages of 2.5 t to 15.0 t. The tests continued until a 40 mm

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horizontal displacement (Uu=40 mm) was reached – according to the standard procedure BNbD 50.01-16; MNS 3388-1982; CR 24.13330.2011.”


a)
b)
c)

Fig. 1. Testing stages: a) Displacement measurement; b) Soil damping; c) Casing pipe being installed.

4 Field test results

The horizontal displacements were measured at the initial moment (t=0) and, subsequently, at regular intervals under load Q=2.5-15.0 t in 2.5 t stages (Table 2). Three hours after the completion of the test, the 15.0 t load was removed in 5.0 t stages and the elastic displacement was measured (Figs. 2, 3). The test results are shown in Table 2 and Figures 2-4.

Table 2. Horizontal displacement in Piles I and II

Load, t	**Pile**	**Horizontal displacement U, mm**									$\sum U_i$
		0`	**30`**	**30`**	**30`**	**30`**	**60`**	**60`**	**120`**	**120`**	
2.5	Pile 1	0.015	0.132	0.267	0.433	0.603	0.809	0.995	1.218	1.432	1.432
	Pile 2	0.019	0.111	0.238	0.399	0.607	0.822	1.051	1.342	1.662	1662
	Average	0.017	0.122	0.253	0.416	0.605	0.816	1.023	1.280	1.547	1.547
5.0	Pile 1	1.882	2.098	2.296	2.509	2.753	3.560	4.320	5.096	5.928	6.753
	Pile 2	2.192	2.404	2.635	2.875	3.126	3.987	4.833	5.553	6.306	7.101

	Average	2.037	2.251	2.465	2.692	2.939	3.774	4.576	5.325	6.117	6.927
7.5	Pile 1	7.591	7.608	7.633	7.667	7.713	8.744	9.771	10.777	11.782	11.782
	Pile 2	7.721	7.772	7.848	8.301	8.692	9.362	9.825	10.513	11.197	11.197
	Average	7.656	7.690	7.741	7.984	8.203	9.053	9.798	10.645	11.489	11.489
10.0	Pile 1	12.792	12.827	12.864	12.896	12.960	14.235	15.867	17.555	19.244	19.244
	Pile 2	12.476	12.561	12.753	13.172	13.286	14.581	16.094	17.447	19.578	19.578
	Average	12.634	12.694	12.809	13.034	13.123	14.408	15.981	17.501	19.411	19.411
12.5	Pile 1	20.825	20.866	20.913	20.936	21.005	22.439	23.521	24.937	27.624	27.624
	Pile 2	20.897	20.983	21.030	21.285	21.223	21.839	23.279	25.195	28.221	28.221
	Average	20.861	20.925	20.972	21.111	21.114	22.129	23.400	25.066	27.923	27.923
15.0	Pile 1	29.002	29.055	29.123	29.174	29.228	31.163	33.135	35.130	38.723	38.723
	Pile 2	29.104	29.231	29.378	29.612	29.973	31.491	32.912	35.104	37.605	37.605
	Average	29.053	29.143	29.251	29.393	29.601	31.327	33.024	35.117	38.164	38.164

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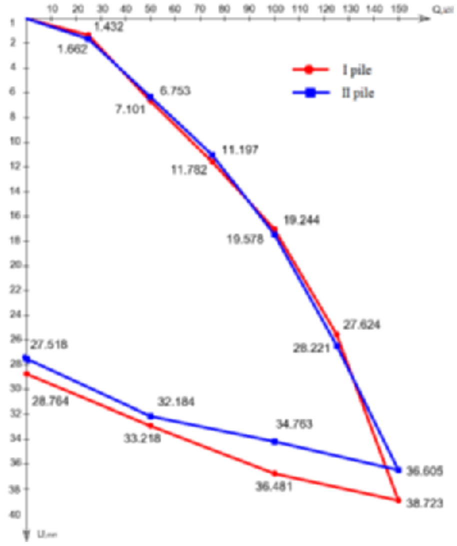

Fig. 2. U=f(Q) diagram for Piles I and II.

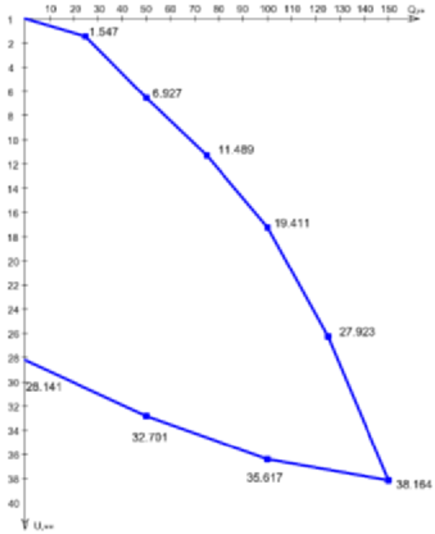

Fig. 3. Averaged U=f(Q) diagram for Piles I and II.

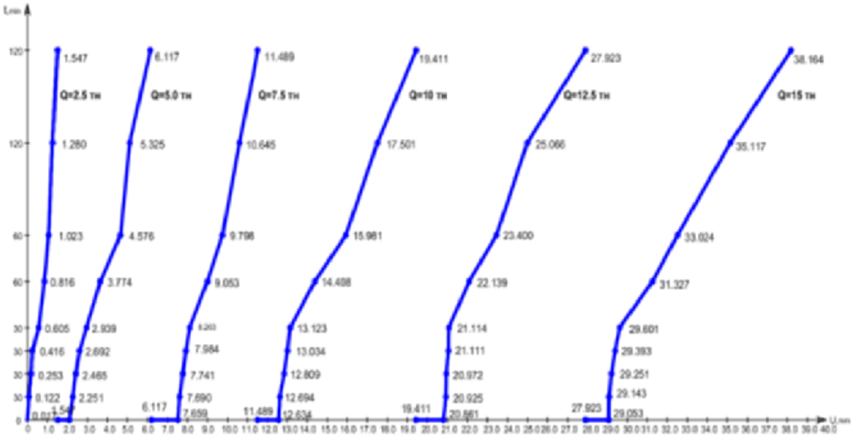

Fig 4. Averaged U = f(t) curves for Piles I and II under load Q= 2.5÷15.0 t

5 Numerical experiments

The horizontal pile load test in damped sandy loam soil was followed by numerical experiments in PLAXIS 2D (PLAXIS official website) and pile performance modelling by using the finite element method [12]. The soil performance is shown in Table 1. The results of numerical tests are presented in Figures 6-9.

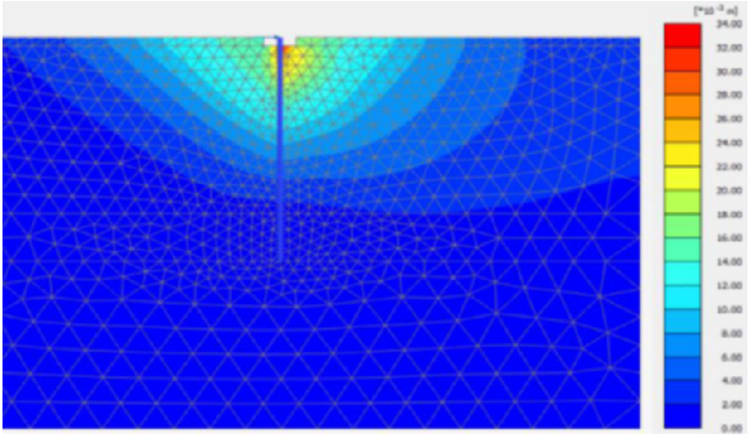

Fig. 5. Horizontal displacement in soil at Q6=150 kN.

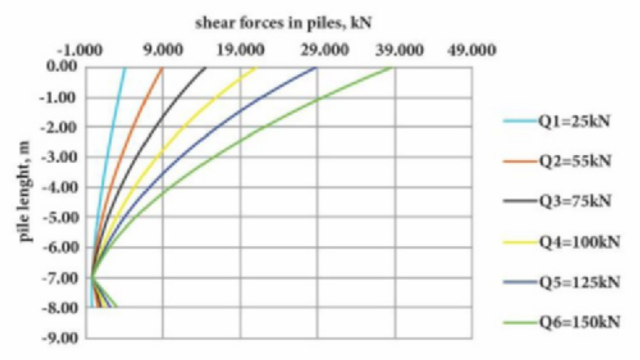

Fig. 6. Horizontal displacement in piles under Ux=38.49 mm.

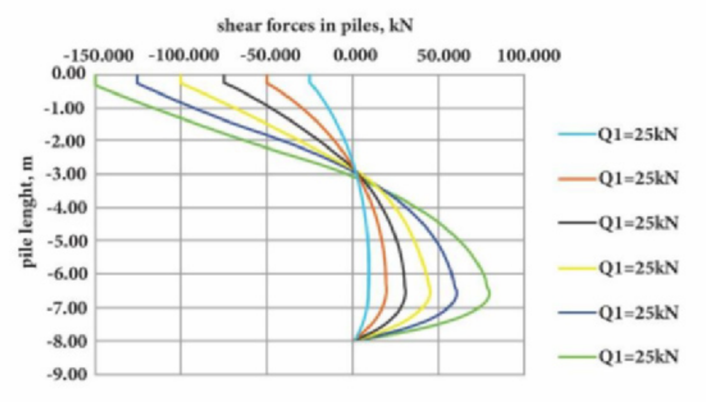

Fig. 7. Transverse stresses in piles, Qx=79.58 kN.

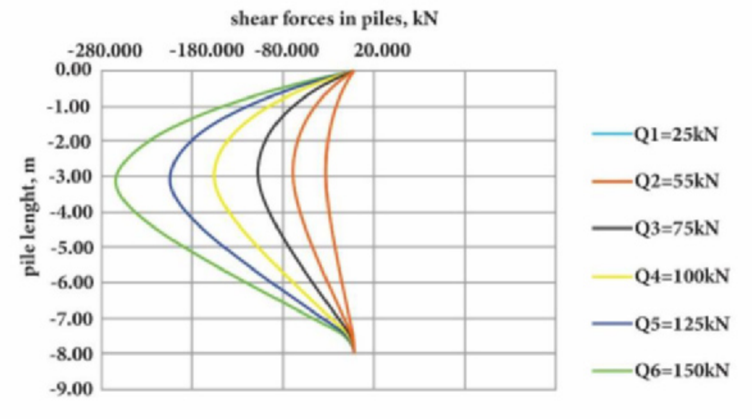

Fig. 8. Bending moments in piles, Mx=262.9 kNm

6 Conclusions

1. The test results have shown that the maximum horizontal load on pressure-injected concrete piles I and II with a diameter of 0.6 m and a length of 8.0 m, installed in damped loessial sandy loam soil, measures 15.0 tons. In Pile I, the horizontal displacement measures U_u=40,0mm >U_{corr}^{P-I}=38,723 mm, and in Pile II U_u=40,0mm >U_{corr}^{P-II}=36.605 mm, the average horizontal displacement in both piles under the load of 15.0 ton being $U_{corr}^{avr} = 38.164\, mm$.

2. The horizontal displacements tend to occur most intensely immediately after loading at t=0, then, during the first two hours, they slow to moderate, and, subsequently, exposed to 10.0÷15.0 ton load within hour hours, increase again. The increase in horizontal displacement is due to primary filtration consolidation and movement of pore water, caused by stage-wise application of 2.5 ton to 15.0 ton load.

3. During unloading from 15.0 ton down to 0.0 ton, the elastic displacement in Pile I measuress 9.658 mm and in Pile II 9.087 mm, the average being 9.523 mm. Elastic displacements account for approximately 25% of horizontal displacements, enabling a conclusion that elastic resistance occurs due to incomplete removal of pore water after horizontally-directed primary filtration consolidation.

4. The numerical modeling of ultimate horizontal load has shown that the displacement measures Ux=38.49 mm, the horizontal force Qx=79.58 kN, and the bending moment Mx=262.9 kNm. The discrepancy between the horizontal displacement values, measured in the course of the field test and with the use of numerical modeling, is less than 5.0%, which is within the allowable limits.

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